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ABSTRACT

The two chapters of this monograph deal with the issue of the existence of a perceptual grammar that influences reading proficiency, particularly initial reading proficiency. The first chapter indicates the importance of studying reading and writing in terms of readers' and writers' knowledge of visuo-spatial processing rules. It discusses research into the processing of single shapes, the processing of arrays of shapes, and the production of shapes, and it suggests some readily testable hypotheses relating to the grammar of two-dimensional space. The suggested hypotheses deal with five areas: (1) mirror image confusions and writing reversals, (2) internal (mind's eye) scanning, (3) differences between production and recognition of graphic symbols, (4) readers' use of Cartesian spatial rules, and (5) low versus high skills. The second chapter describes Lila Ghent Braine's work indicating that children have a concept of "right-side-up" different from that of adults and discusses evidence that this concept contributes to children's rotation errors in copying symbols. It also discusses factors that contribute to children's mirror image confusions, outlines some practical implications, and offers hypotheses about reasons for the persisting orientation errors of children who have difficulty learning to read. (GT)

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IRA series on the development of the reading process

SOME PERCEPTUAL PREREQUISITES FOR READING

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Foreword

It is particularly fitting that the International Reading Association should publish this *Series on the Development of the Reading Process* for the volumes in this series exemplify the value of reading—the value of the printed word. The Series originated in a four-week summer institute at the University of Delaware. Those fortunate people who were able to participate in the institute counted it an enriching experience. How does one share such an experience at a reasonable cost with thousands of others who will wish they might have been present to participate? Through the medium of print. In this IRA series, participation in that unusual institute is available to all interested readers.

The volumes in this series represent more than just a series of papers presented at the institute. They incorporate ideas raised in the discussions at the institute and new developments interpreted through perspectives engendered by the institute.

This *Series on the Development of the Reading Process* deals with important basic issues that are fundamental to understanding the changing nature of the reading process as both the process and the child develop. In the literature on reading, these issues—such as the development of the child's cognitive abilities, the development of the child's semantic system, the child's changing conceptions of language, and the developing relation between listening and reading—are often referred to knowingly as if they are well understood or as if mere reference to them will prove a point. In this series, however, each volume deals with one such basic issue in a comprehensive way and specifically in relation to learning to read.

The person with the vision to develop the institute and with the wisdom and commitment to see that the fruits of the institute were made available to others is Frank B. Murray, editor of this series. The International Reading Association and all who value a deeper understanding of the development of the ability to read are indebted to him for his vision and his labor.

WALTER H. MACGINITIE

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The International Reading Association attempts, through its publications, to provide a forum for a wide spectrum of opinion on reading. This policy permits divergent viewpoints without assuming the endorsement of the Association.

Preface

In this seventh monograph of the IRA series on the development of the reading process, the authors, Uta Frith and Juliet Vogel, take up the issue of the existence of a perceptual grammar which influences reading proficiency, particularly initial reading proficiency. Throughout this monograph series there has been developed the theme that reading cannot be understood apart from the basic mental mechanisms. Thus, we can invariably expect to find that reading problems, errors, etc. are merely instances of general characteristics of the general perceptual, cognitive, information processing, and linguistic systems.

The ubiquitous letter reversals and rotations, the classic confusions between *b d q* and *p*, are analyzed in this monograph as aspects of the child's conception of two-dimensional space in which a "perceptual upright" exists, often different from the conventional upright of some letter symbols, and in which, for example, left to right orientations are not significant features. Consequently, the child's writing and penmanship errors are the lawful consequences of the developing grammar of two-dimensional space in this analysis.

The series is organized around the notion that the child's reading behavior, among other things, is a developmental phenomenon. This means that, like other developmental phenomena, there are certain necessary and sufficient conditions for it and that it changes both quantitatively (it becomes faster and more efficient) and qualitatively (different and more complex models are needed to explain it) as the child ages. The series will examine the development of reading from the perspective of the perceptual, cognitive, neurological, and linguistic prerequisites for it; specific factors in its acquisition; and factors which lead to the enhancement of the reading skill once it has been acquired.

During the summer of 1974, the Society for Research in Child Development, with the support of the Grant Foundation of New York, sponsored a four week interdisciplinary institute at the University of Delaware on Reading and Child

Development. The thirty-three institute faculty were researchers in the disciplines of psychology, psychiatry, education, linguistics, neurology, sociology, and the law. Each spent from three to five days at the institute, both formally and informally presenting the applications of their research to the field of reading.

The institute participants were advanced doctoral students and postdoctoral faculty from various disciplines who had an interest in and commitment to research in reading. They were present for the full four weeks, and some of them are contributing authors to this IRA *Series on the Development of the Reading Process.*

The success of the institute, upon which this series is based, was due to the energies and talents of many people. In addition to the dedication of the participants, faculty, and administrative staff (whose names appear elsewhere in this issue), the staff of Clayton Hall and the Department of Educational Studies of the University of Delaware, and the members of the Long Range Planning Committee of the Society for Research in Child Development contributed substantially to the planning and execution of the institute. Finally, the series itself was greatly improved by the editorial assistance of Lloyd Kline and Faye Branca of the International Reading Association.

Frank B. Murray

The World of Two Dimensional Space

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It has become fashionable to argue that perceptual factors are of little interest in reading research. This is understandable as despite many attempts so far no clear relationships between perceptual development or perceptual pathology and reading performance have been demonstrated. While critics grant that there are perceptual prerequisites for reading such as are used in reading readiness tests, they point out that even young infants may learn to read long before readiness tests would allow this. They also point out that people with severe perceptual deficits may nevertheless be able to read, and, conversely, that on the whole poor readers are unimpaired on perceptual tasks. How then can there be a case for researching into perceptual factors in reading and writing?

If perceptual factors in reading are equated with letter recognition or word outline recognition, as is often the case, one would indeed have to conclude that this has little to do with skilled reading. From this point of view one might concede that perceptual factors are relevant in the early stages of reading acquisition (bearing in mind that these are quickly passed through by most children); and that perceptual factors are also involved in reversal and rotation errors that may occur as a persistent problem in poor readers (bearing in mind that this is a very minor problem). The aim of this chapter is to show that despite this disillusionment it is interesting and important to understand reading and writing in terms of visuo-spatial processing rules. Perceptual processes include of course much more than letter recognition and letter reversals and the methods of studying them have become more sophisticated, so that with wider theoretical notions and improved methods the interest in the perceptual aspects of reading should only increase. It cannot be denied that one basic aspect of reading, whether on the skilled or unskilled level, is and remains a visuo-spatial task.

Let us look briefly at the development of the perception of two dimensional space and the flat shapes that inhabit this strange world. Flat surfaces and graphic shapes are the medium of written language, the raw materials as it were. Hence, it is appropriate that reading research should start here, although it is a domain where a vital ingredient of reading, that is language content, or indeed any symbolic content, is not considered. What is considered are some perceptual and motor strategies for handling two dimensional space. These are basic prerequisites for reading and writing to have developed as efficient human communication systems. Although marks on a flat surface may accidentally occur in nature, we are dealing essentially with a man-made and indeed highly sophisticated world that constitutes pictorial and graphic symbolic representation. It is wise to limit this discussion to graphic symbols only, that is, any marks, scribbles, shapes or figures, that could be or are letters or signs useable in writing systems. These graphic shapes are not themselves invested with meaning but are typical potential carriers of meaning.

A framework for looking at the developmental progress of perceptual abilities is provided by theories such as that of Piaget and Gibson. A discussion of these important theories is outside the scope of this chapter. As an example of a detailed experimental analysis of children's perception of graphic shapes, Braine's work (see bibliography) will be summarized briefly. This work concerns processing strategies that people use when they look at graphic shapes in particular orientations in two dimensional space. People bring strategies to the task which seem to some extent "given," that is, possibly innate, though modifiable by experience. These strategies or rules play a significant role in the perceptual act. In very general terms, there is support for the notion that two dimensional space is not neutral but polarized. An excellent review of this is provided by Howard and Templeton (1966). Thus, for example, information presented in the left and right fields is not identified equally well. Many shapes also are not neutral as regards their orientation: they have a perceived upright. Orientation judgments may *derive from* processes involved in shape perception. Braine also hypothesizes that parts of

shapes are processed sequentially, so that one can distinguish between the starting point of processing and the subsequent direction of processing. In this sense, she talks about the internal ordering of visual patterns. The notion of a micro-analysis in discrete successive steps of a superficially unitary stimulus makes this theory particularly suitable to look at a most puzzling problem in shape perception, that under certain conditions only part of a figure need be processed for correct identification. This problem may be general for any perceptual process, but is particularly relevant to reading, which may well depend on such short-cut processing for normal speed and efficiency.

A different approach to perceptual processing of graphic shape considers orientation as a "feature" of shapes, similar to size, color or closure. This notion has been put forward for example by Gibson (1969) who discusses evidence that young children pay little attention to orientation and become aware of this feature only later as a result of specific experience with graphic symbols.

Processing Single Shapes

There is now evidence from a large number of experiments carried out by Braine and her associates that many flat shapes have preferred orientations. These experiments have been carried out with children of different ages and in different cultures; they use such methods as simple upright judgments, multiple choice judgments, placement of shapes in preferred positions, matching, copying, tachistoscopic recognition, discrimination training, and transfer. A shape can be readily judged as upright or upside down by a four-year-old. The judgments are consistent and reliable. They are particularly reliable if the shapes are presented in the perpendicular plane. In this case, upright and upside down has an unequivocal meaning. It cannot be taken for granted that "up" in the air is the same as "up" on a piece of paper lying flat on a table, and young children are indeed confused about this and do not know whether "near" or "far" in this case is the same as "up."

Braine hypothesized, on the basis of experimental evidence, that processing strategy determines the perception of

the upright. Spatial processing has a direction and this is downward "scanning." The term scanning does not imply physical movements of the eye but is purely a metaphor. If scanning has a downward direction, for efficient processing the starting point should be at the top of the figure. However, young children are attracted first by the most salient feature of the shape, regardless of its location in the shape. If the salient feature is at the top it happens to be a good starting point for the downward scan, and the shape is easy to process. As a result the shape is considered upright. If the salient feature is at the bottom, a conflict between downward scan and the involuntary attention to the salient feature arises. The shape is then considered upside down. Thus, what the child expresses in the upright judgments is whether the shape is "right" or "wrong." The child reacts to a conflict between processing tendencies.

With development, the attraction of the salient feature and its potential rivalry with the directionality of processing becomes less. Thus with increasing age the downward scan tendency remains, but the starting point changes. After five years of age the starting point is actually at the top of the shape, the top being defined by the spatial framework external to the shape. Thus older children attend first to the top of a shape rather than to the salient feature.

The notion of the focal (salient) feature is not identical to the notion of a distinctive feature. A salient feature may or may not be at the same time a distinctive feature. A distinctive feature is that aspect of a shape that is critical to the identification of the shape and/or its differentiation from another shape. The focal feature (e.g., a gap in the shape, a black area, etc.), attracts the attention of the young child involuntarily and disproportionately. At later ages, attention to shape details comes under voluntary and more flexible control. This concept can be well accounted for by Piaget's mechanisms of centration and decentration.

Experiments with older children and adults showed that upright judgments are still rule-governed, but these rules differ in certain ways. A developmental hierarchy of orientation perception is suggested. The earliest distinction the child makes is between upright and non-upright. The category non-

upright includes shapes that are upside down and sideways. These latter two categories become differentiated at the next stage, and at a further stage the sideways category is differentiated into left and right. This model implies that we can't expect a child to make correct left/right distinctions unless he has learned to make the other distinctions first.

Processing strategies used by older children and adults still give evidence of a downward scanning tendency which is now properly called a top to bottom scanning tendency. this refers to the vertical axis of space. Much less is known about the horizontal axis. So far no evidence has emerged as to whether there is directionality and, if so, whether the left or right side of a shape may be a starting point for processing. In any case it seems highly probable that the vertical and horizontal dimensions of two dimensional space are not exchangeable and are of quite different strength and value.

Processing Arrays of Shapes

It is important to distinguish between the processing of singles and the processing of arrays of shapes. Different rules and strategies for handling this much larger space seem to apply. Such sequential strategies not only extend over a large space but also take up longer times. However, even with arrays, much of the work, though not all, is based on exposures too brief for actual eye movements to occur. Hence the term *scanning* must still be regarded as a metaphor. Experiments again distinguish processing in the vertical and horizontal dimensions. As before, the plane of presentation, i.e., perpendicular or sagittal, is of relevance. It can in no way be assumed that scanning of shapes is the same regardless of the plane. As Braine pointed out, the old fashioned desks with their slanted surface may well have been particularly helpful for beginning readers. In some unpublished work by Goodnow, when asked to match the top in a display of several dots on a page presented sagittally, to a display presented perpendicularly, children of age three or four equate the dot nearest to them with the perpendicular top. After five years of age children are able to define the top of an array on a flat sagittal surface in the same way as the top of a single shape, namely in terms of an external

spatial framework. This framework is independent of the plane of presentation and of the particular shapes used.

As far as the vertical axis is concerned, a clear top to bottom downwards scanning strategy is found for arrays of shapes, the same as for single shapes. Scanning along the horizontal axis of an array shows less asymmetry compared with the vertical axis. There is some evidence that the spontaneous starting point of horizontal scanning is at the left and that the spontaneous direction of scan is to the right, at least in subjects around twelve years and over. In young children, the data are less reliable and might be interpreted in more than one way. One possibility is that the internal ordering of visual patterns goes in a rightwards direction, but at an early stage of development the starting point would be wherever fixation happens to be (some salient part of the pattern) and not necessarily at the left. It seems that it is only around the age of twelve years when the starting point becomes invariably the left end of a pattern. It is possible that hemisphere lateralization plays a role in this. It is important to note that these findings apply to non-alphabetic material and that these results have also been obtained with Israeli subjects who have a right to left reading habit.

Producing Shapes

The rules that govern the production of graphic shapes have been investigated in particular by Goodnow (1972, 1973) and corroborate as well as complement Braine's studies of perception. Producing shapes requires processes that are extended in space and time and involve real physical movement rather than hypothetical attentional scanning. Some rules which Goodnow has described, such as starting rules and progression rules, are analogous to the rules for internal ordering of patterns. Writing movements tend to start at the top and go down for vertical lines; movements tend to start at the left and go to the right for horizontal lines. In addition, in graphic production, vertical lines come before horizontal lines, and for a sequence of lines the writing movement tends to follow a smooth continuous threading course. Again, just as on the perceptual side, consistency in a

left-right direction is established more slowly than consistency in a top-bottom direction or threading. These rules seem to be fairly consistent and already stable at an early age (five years).

Cultural differences seem to be more important for production than for recognition processes. Goodnow et al. (1973) have shown that Israeli children have some copying rules that are in quite the opposite direction to those found in American children. There are also some common developmental trends and the specific differences could be explained in terms of specific writing styles. Looking at developmental progress, production rules do not seem to follow a parallel time course to recognition rules. The nature of the relationship between the two rule systems is as yet obscure.

This very brief summary indicates that much investigation is still needed in order to understand the processes of visuospatial perception. Examples of open questions are given by the following hypotheses which could be readily tested experimentally. The general goal set by hypotheses derived from the work of Braine, Kolers, and Goodnow is the elaboration of a grammar of two dimensional space. This grammar may have to be different for perception and production. It must take into account developmental stages, as it is clear already that rules used by young children are different from those used by adults.

Some Testable Hypotheses on the Grammar of Two Dimensional Space

1. The Mirror Image Problem

The perennial puzzle of mirror image confusions and writing reversals is intricately linked to our ignorance about the grammar of two dimensional space.

From Braine's work we may assume that single shape processing has a specific directionality in the vertical dimension. However, findings are much less clear in the horizontal dimension. This might be because of the type of shape used in the experiments: the shapes are symmetrical around the vertical axis, and hence the left and right sides look identical. It would be interesting to extend Braine's experiments using the same techniques to shapes that are asym-

metrical (b) or symmetrical around the axis (B). Such shapes have different left and right sides.

Two hypotheses can be put forward about processing single shapes along the horizontal axis. First, one might assume that this is analogous to processing along the vertical axis; one might further assume in analogy with processing arrays of shapes that the directionality of processing is rightwards and that the starting point of processing is dependent on the level of development. Thus, young children would use the salient feature as the starting point, while older children and adults would use consistently the left side of a shape as the starting point, regardless of the position of the salient feature. An alternative hypothesis would state that processing along the horizontal axis of a single shape has no stable directionality at all.

Mirror image confusions can be explained by either of the two hypotheses. But at this stage perhaps a better case can be made for the first hypothesis which assumes sequential processing along the horizontal axis of a shape. However, before addressing ourselves to the problem, it is necessary to define it more precisely. Braine reported that mirror image type confusions are found with non-identical shapes which implies that the problem is not primarily one of looking at mirror image constellations. The problem concerns more generally shapes that are asymmetrical about the vertical axis (i.e., that have distinctly different left and right sides). If one sees such a shape that points either to the left or to the right, one might later not remember which way it was pointing. This failure to remember may result in a reversal of the orientation of the shape which is, of course, by necessity a mirror image. It is important to point out that children do not confuse mirror images when they are seen next to each other; that is, they can tell that the two shapes are different. What they are confused about is "which is which." Thus as soon as they have to remember a particular shape of the mirror image pair, they make errors. Equally, if only one shape that is asymmetrical about the vertical axis is to be remembered, the child may forget which way it is pointing.

In order to carry out experiments it would seem wise to restrict initial analysis to simple shapes with only one

presumed salient feature, such as b or d. In this case one might assume that the loop is salient for young children and would attract their attention first. Thus they should start processing at the loop in the letter b, and also at the loop in the letter d. The internal scan would only then, as a second step, "move" on to other shape details. If the internal representation of visuo-spatial processing is in terms of the actual operations carried out (as Kolers suggests) then the letters b and d would be represented identically: loop, followed by vertical line. Thus the hypothesis distinguishing directionality and starting point of processing would readily explain why young children confuse memory images about "one-sided" shapes, and why older children do not. One would expect that older children would have a stable starting point, and hence would easily differentiate the two shapes. When the left side is processed first consistently, then b is represented as "vertical line followed by loop" and d is represented as "loop followed by vertical line."

To summarize, experiments could be carried out using simple shapes whose focal feature is on one side. It is doubtful from pilot studies that young children prefer one side over another in a simple aesthetic judgment situation. They may genuinely not "take in," i.e., internally represent and thus remember which way a shape is pointing—in other words, on which side the focal feature is. Mirror reversal is characterized by bringing the focal feature to the other side. If processing in young children starts with the focal feature, then both forms of the shape will be processed in the order: focal feature (which is the identical shape detail), rest of the shape (which is another identical shape detail). It is hypothesized that the memory representation of these operations is indistinguishable. Hence, the typical confusion results which seems to be characterized by equating mirror images.

Older children would be able to suppress the centration on the focal feature and instead use a stable point for starting processing. To be stable, the starting point has to be defined in terms of the surrounding spatial framework. Thus, just as "top" can be defined by the older children in relation to an external framework, so "left" can be defined in terms of the same framework.

Experiments that could test this hypothesis would have to use a technique which enables one to distinguish starting point of processing and directionality of processing in the horizontal dimension. The visual masking technique, described for example by Turvey (1973), would perhaps be helpful. By masking at very short intervals during the supposed temporal sequence of processing, it could be tested whether indeed the predicted parts of a shape have been processed or not at particular points in time. Another technique would be to present the sequence of implied scanning slowed down with gaps in between. Thus, for the letters b and d the presentation of the vertical followed by a circle and the circle followed by a vertical could be studied. One might predict that a vertical followed by a circle would always be interpreted as a b, even if the spatial arrangement clearly is that of a d.

A third method would be to provide an additional but dominant focal feature for these shapes. This super-focal feature could be placed on the same side (e.g., the left) regardless of whether the shape was shown reversed or not. By using such an artificial method the child's attention may be captured and thus will always be on the same side of the shape at the start of processing. If this were successful, even young children would not be confused by mirror images. However, there is an alternative hypothesis that would predict that such a manipulation would fail to result in non-confusable representations. This hypothesis would simply state that in young children representations of scanning operations do not retain information about the implied order of the operations. In any case it would be extremely interesting to investigate the limitations of memory representations of two dimensional shapes.

2. The Mind's Eye Scan Problem

The notion of directionality in visuo-spatial processing of single shapes, and indeed the assumption of an internal scan, provokes analogies with eye movements. However, it is an open and very challenging question how far this analogy holds. An investigation relating real scanning and implied internal scanning would be of great interest, particularly in a

developmental framework. It could be hypothesized that external scan is developed prior to internal scan and that attention does make use of real motor strategies which are internalized. This hypothesis would fit in well with Piaget's notions of sensorimotor schemata and their fundamental relationship to thought processes.

In their own right the study of physical scanning strategies would be of interest. Efficient movement strategies in two dimensional space could be studied in the framework of perceptual learning theories. This is the realm of eye movement studies. With the availability of more and more sophisticated techniques, new results in this area can be expected in the near future. Some important insights gained so far are, for example, that visual input is discontinuous (as eye movements are abrupt jumps) and that the units of input, determined partly by the eye movements themselves, are hierarchically structured (Gaarder, 1970).

It is much more difficult to study internal scan. The crucial point of this notion of internal scan is that it is supposed to be a process in time that, like physical scanning, does not absorb stimuli in a unitary fashion but, on the contrary, follows a path of successive analyses of parts. As Lashley (1951) has pointed out, high-speed sequential actions require the operation of organizational schemas. In processing single shapes, the sequential actions involved must be extremely fast: thus the assumption of an underlying program is inevitable. The possible nature and function of such programs has been described by Keele and Posner (1968). One way of studying internal scan might be to present parts of shapes bit by bit on a movie film, varying speed and spatial location. This might be a means of discovering presentations that are congruent and incongruent with specific scanning programs. Directionality in the vertical axis would have to be studied separately from directionality in the horizontal axis. The role of the focal feature as a "distractor" of attentional scan could also be studied in this context. Visual masking techniques would appear to offer promising possibilities. These techniques are designed to apply a microanalysis of shape perception by cutting off processing operations at different stages. This segmentation would presumably reveal how much of a

particular shape had been processed at a particular point in time.

Experiments with large shapes might also be useful. Large shapes have to be scanned "physically," i.e., in terms of real eye movements, for recognition to occur. Thus they might provide a method for circumventing the mind's eye scan. It would be interesting to find out whether rules applying to arrays of shapes would also apply to single very large shapes. It has often been pointed out that large size print aids reading and is especially helpful in the beginning stages of reading. With poor readers one can usually bring about an instant improvement by presenting words in large letters. Brain-damaged patients suffering from alexia can also be helped by increasing print size (Woods and Pöppel, 1973). No satisfactory explanation exists for this phenomenon. One might hypothesize that visuo-spatial strategies can be more easily applied and practiced with units on a large scale. As a further step one could hypothesize that well-established scanning strategies involving large scale movements can be internalized and then applied to small shapes as well. This hypothesis is based on Piaget's (1951) notions on the interiorization of sensorimotor activities.

3. The Production—Recognition Problem

Many observations point to the independence of rules for writing movements and rules for recognizing the end products of writing. Although both types of rules become automatic and hence unconscious in the skilled reader, at first much conscious effort is required to familiarize the eye as well as the hand with graphic shapes in two dimensional space. It can be hypothesized that motor rules have to be more rigid and less variable for an automatic and effortless execution of the movements. On the other hand, recognition rules have to be more flexible and less rigid for efficient recognition because the material to be recognized varies considerably, as for example, letters in different handwriting styles.

To test this hypothesis one could study how very young children draw graphic symbols. It would be predicted that the motor programs acquired through practice would be difficult to

change. However, given the same amount of practice for recognizing shapes, a change in appearance would have little effect on recognition. One experiment supporting this notion has been carried out by Frith (1974). If they are independent, it is to be expected that either recognition rules alone or production rules alone may be impaired. If recognition is intact and production is impaired, one would expect a pattern of excellent reading together with poor spelling ability. This combination indeed exists and is by no means rare. As documented in clinical studies (Benson and Geschwind, 1969), there are cases of "agraphia" without "alexia" after localized brain lesions. Conversely, there is a condition after brain lesion where patients can write but not read. These patients are even unable to read their own writing, unless they can trace it with actual finger movements.

It would be necessary to take into account how different modality systems affect rules in two dimensional space. It is possible that production rules relate more closely to tactual than to visual exploration. It would be desirable to extend Braine's work on orientation preferences to this area. Reading and writing Braille has been studied very little. Since each letter of the Braille alphabet is a dot pattern of different spatial relationships, its use in investigations of spatial processing rules would be particularly appropriate.

4. The Cartesian Framework Problem

In order to describe space and spatial relations, a framework is necessary, but this framework may differ in terms of its anchors and its stability. One's own body, for example, may provide a frame of reference. In this case the spatial relationships are egocentric, that is, they do not apply to other "bodies," and they are also unstable as they change with one's position in space. Thus, left becomes right and right becomes left when one is at opposite sides of an object. As formulated by Piaget, and recently discussed by Pufall and Shaw (1973), development proceeds from a "self-reference system" to an "objective reference system." An objective reference system, such as the Cartesian framework, is independent of the position of the observer in relation to the

object. Thus, it is a stable system within which it is easy to communicate. The terms "top/bottom," "East/West" can be readily understood. The Cartesian system has been adopted by many different cultures. Nevertheless, we must not forget that it is an arbitrary system.

It is interesting that Cartesian coordinates have been used for writing systems from earliest times, although there are exceptions to this rule. For example, there exists a disk found in Crete, now owned by the Museum of Iraklion, where the writing symbols are arranged in a spiral, an arrangement which is not uncommon. In many archaic writing examples the arrays of symbols have a variable form and single symbols may also vary considerably in their orientation. The application of a Cartesian system may be closely linked to the development of writing systems. Its clarity and stability has no doubt influenced the development of reading and writing skills. Rectangular pages, straight lines, letters aligned with each other, regular height and width, are accomplishments we take for granted in two dimensional space. But these rules are no more "inherent" or "absolute" than rules of any other system of reference.

When the visual layout of a text does not obey Cartesian rules, would we predict impairment for the efficient or the inefficient reader? It might be a useful exercise to imagine a conglomeration of symbols strung together with the single rule that a following letter should be adjacent to the previous one. This would result in a completely meandering pattern of letters whose direction and whose beginning and end would be difficult to see that "right of" a letter would not necessarily mean "after." The "beginning" need not be the "top." In contrast to this, we could imagine the conventional layout for text using the identical symbols. Comparing the two arrays we would predict that we could read, copy, or remember the latter much better than the former. This is because we are familiar with the rules. We know that the following letter when we come to the end of the line is the first one in the next line. We know that one starts at the upper left and finishes at the lower right, etc. While the efficient reader would have difficulty reading in a non-Cartesian framework, the reader who makes little use of Cartesian rules anyway would presumably show no impair-

ment. One could also hypothesize that a reader who has difficulties in spatial processing would get no advantage from using a highly rule governed system in preference to one with few rules, whatever the system. Within limits, the more rules there are, the more one can take for granted: if much of the task of reading is predictable, it becomes easy and efficient.

5. The Low-Skill/High-Skill Problem

What difference is there between a person who is highly skilled at using the rules of processing graphic shapes and one who is unskilled? In the traditional study of motor skills the change from unskilled to highly skilled performance has often been explained by a change in strategy. Highly skilled performance may imply the use of higher order units (or chunks) and this may result in a bigger span of apprehension. In reading, single shape processing strategies may be able to be applied to units that are bigger than a letter, maybe a word, a line, a paragraph or a page. If reading skill progresses with the size of the single graphic unit, then certain aspects of the obscure phenomenon of speed reading could be accounted for. Thus visuo-spatial processing rules are probably of particular importance in highly skilled reading, and not just at the early stages of reading.

It is now an obvious question to ask whether the unskilled reader is unskilled in terms of the processing rules for two dimensional space. So far, the search for perceptual deficits in reading disability has been very disappointing. For one thing, the aspects looked at were often too simpleminded. On the other hand, an analysis of visuo-spatial processing rules depends on techniques that have only been developed recently.

Perceptual deficits must account for part of the reading disabilities, since reading is partly a perceptual task. yet they must be extremely subtle as they have often eluded research. The deficits also must be extremely specific to account for specific reading failure. Mechanisms such as "sequencing" or "cross-modal integration" would seem too general not to be associated with other obvious deficits. The deficits should only apply to the processing of graphic shapes and not generally to

pictorial processing. This is not the same as saying that the deficits must apply to material with language content. We are at this level of analysis concerned with the raw material that may be used to convey language but by itself is neutral. An experiment replicating Bakker (1967) and extending his findings (Hayes, 1974) showed that ten-year-old poor readers had impaired memory not only for letters, but also for letter-like shapes. At the same time, poor readers were not impaired on pictures. This lends support to the notion that perceptual deficits are neither general ones nor specifically related to language. The type of deficit we must expect to find is more subtle and, at this stage, we may describe it as a difficulty in handling graphic symbols that either are or could be letters.

The rules governing the processing of single shapes and arrays of shapes are particularly promising candidates for various types of deficits. There are two main reasons for this; these rules ("how a shape is perceived") may relate intimately to "what is perceived." One of Kolers' (1973) most challenging hypotheses is that the operations involved in processing shapes are all that is necessary to be stored for the material to be recalled. This would imply that the quality of representation of graphic input in memory depends entirely on the quality of the processing operations. Deficit in the initial processing would entail a memory deficit. Deficits in processing rules for single shapes and arrays are likely to be independent of one another and presumably even more likely to be independent of processing rules for objects in three dimensional space or pictorial representation.

Once the grammar of two dimensional space has been described systematically by observing highly skilled subjects, lack of competence in this skill can be defined. However, some reasonable hypotheses about the nature of this particular incompetence can already be formulated, such as instability of the direction of scan, inability to use "top" consistently as a starting point of processing, lack of knowledge of rules of spatial representation, incomplete processing, inadequate memory representations.

Conclusions

Visuo-Spatial Processes Are an Important Element in Reading

Just as knowledge of the auditory aspects of a language makes listening comprehension possible, so knowledge of the grammar of the visuo-spatial medium that is used by written language makes reading comprehension possible. Because we are extremely familiar with our own first language, we find it difficult to imagine to what extent speaking and listening depend on knowing rules of which we need have no awareness. Because we are extremely familiar with print and script, we often tend to forget that reading does depend on knowing the rules of visuo-spatial exploration. Incidentally the word "visual" could be omitted, as we can extend this notion to reading Braille, a task we all know can be accomplished without any visual experience.

A simple test of the hypothesis would be to compare the ability of good and poor readers (matched on relevant variables such as age and intelligence) to use the written form of a foreign (or artificial) language. Tasks of copying or recall might be appropriate. If bad readers are less good at these tasks, then language impairment cannot account for their reading disability. Careful manipulation of the variables involved in single shapes (type of symbols) and arrays of shapes (layout of text) should give one clues to the major sources of difficulty. Reading and writing symbols without language content might thus be an interesting method which could be used to investigate specific aspects of reading difficulty.

In reading and writing we use techniques which we can apply to any language we might learn. It is an inescapable conclusion that there is a system underlying reading which is quite independent of language comprehension. Investigating this system will increase our knowledge of the reading processes as well as of perception in general.

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Getting Letters Straight[1]

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When young children are learning to read, they frequently confuse mirror images such as *b* and *d*, and in their early writing they both reverse and rotate symbols. For most children, these errors decrease rapidly during the early school years (Davidson, 1935; Gibson, Gibson, Pick, and Osser, 1962), but they persist longer for some children who have difficulty learning to read (Benton, 1975).

Until relatively recently, young children's rotations and reversals of symbols were thought to reflect lack of sensitivity to the orientation of two dimensional forms (Wohlwill, 1960). Recent research, however, has shown that preschool children are by no means insensitive to orientation even though they do not deal with it in the same manner as adults. This chapter discusses evidence that the children's orientation errors largely reflect their natural rules and strategies for dealing with forms in two dimensional space.

The first section of this chapter describes Lila Ghent Braine's work indicating that children have a concept of "right-side-up" different from that of adults, and discusses evidence that this concept contributes to children's rotation errors in copying symbols. The second section discusses four factors that contribute to children's mirror-image confusions. The final section discusses practical implications. I argue that orientation errors should be a cause for minimal concern and intervention since they decrease naturally as the child's spatial concepts and processing strategies mature; however, the analysis of orientation errors leads to some suggestions for techniques that could be used in a reading readiness program if one wanted to minimize orientation errors. Finally, on the basis of the analysis of orientation errors in normal children, I present some hypotheses concerning reasons for the persisting orientation errors of children who have difficulty learning to read.

The Concept of the Upright: Implications for Processing Two Dimensional Forms

The work of Lila Ghent Braine indicates that young children have two concepts of right-side-up that they can apply to two dimensional forms. First, many objects have one correct orientation with respect to gravity, and at a young age children are able to recognize the upright orientation of such objects. Thus three- to five-year-olds rarely encounter difficulty in telling whether a picture of a familiar object is right-side-up or upside-down (Ghent, 1961; Braine, 1972), and some children as young as two years can be taught to make differential responses to right-side-up versus upside-down pictures (Braine, 1978). Second, preschool children also perceive many unfamiliar forms as having a correct or "upright" orientation, presumably on the basis of form characteristics. Thus, preschool children are willing to categorize unfamiliar forms as upside-down or right-side-up, and for many figures there is considerable agreement among children concerning the upright orientation (Ghent, 1961). Braine's findings concerning the perceived upright of abstract figures have been replicated with several groups of American children (Braine, 1972; Eldred, 1973; Moeller and Goodnow, 1969; Pick, Klein, and Pick, 1966) as well as with children in Iran (Anatovsky and Ghent, 1964) and Zambia (Serpell, 1971).

Children's use of the second concept of upright is of particular interest for this chapter because it raises the possibility that children sometimes treat a symbol as "right-side-up" when it is not in the conventional upright orientation, but rather is upright on the basis of form characteristics. This could happen, for example, with the letter V—in its conventional orientation this letter is upside-down according to the criteria determining the perceived upright to be described below.

Characteristics Determining the Perceptual Upright

According to Braine, young children's judgments of the upright of an abstract form are determined by two characteristics: 1) the orientation of the main lines or long axis of the

form in a vertical direction and 2) the presence of a "focal feature" at the top of the form. A focal feature is a salient feature that catches the observer's attention; it is not necessarily a distinctive feature in the sense of being critical for distinguishing between the figure and others. For very simple forms, Braine provides the further definition of the focal feature as "the differentiating feature of an otherwise homogeneous figure or card" (1972:184). Figure 1 shows some of the simple forms that have been used in studies of children's perception of the upright. As the figure indicates, for these forms the orientation of the main lines and the location of the focal feature do specify the orientation that children select as right-side-up.[2] Children also agree on the "right" orientation of some complex figures with more than one potential focal feature. For such complex figures, Braine suggests that the same two characteristics again determine the perceived upright. However, for these figures she is able to provide no a priori criteria for the focal feature; she gives only the circular definition that the focal feature is one located near the top when the figure is judged to be upright (see Braine, 1972).

Braine proposes that preschool children's perception of the upright is a result of their manner of processing forms. She suggests that, even when an entire form falls within the visual field, the child processes parts of the form serially. This is done

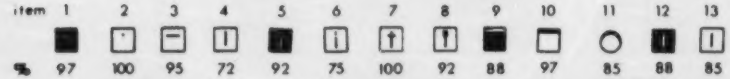

Figure 1. Percentage of children judging the card as upright in the orientation shown here. The focal feature refers to: the single, homogeneous figure in the otherwise empty card in items 1-4, the differentiated portion of the vertical line in items 5-8, and the contour dividing the black-white portions of the card in items 9-11. For items 12 and 13, the centered vertical line was paired with a centered horizontal line, the prediction being that a centered homogeneous line will be considered upright when vertical.

Adapted from Figure 1 of L.G. Braine, Perceiving and copying the orientation of geometric shapes, *Journal of Research and Development in Education*, 1973, *6*, p. 45, with permission of the author and editor.

by means of an internal scanning mechanism (the scanning of the "mind's eye") as distinguished from scanning requiring eye movements. (The degree of similarity between the two types of scanning is not known, as the chapter in this volume by Frith indicates.)

Braine proposes that the preschool child's internal scanning of a figure starts from the focal feature because the child's attention is "caught" by this salient feature, and the scanning then proceeds downward. According to this analysis, a figure with the focal feature on top is processed more easily and therefore is judged to look right or upright.

Braine has found that by the age of six to eight years, children become more reluctant to assign a "correct" orientation to unfamiliar forms, and for many figures they show less agreement than preschool children (Ghent, 1961). Others have also found less consistency in the judgments of elementary school children than typically found for preschool children (Harris and Schaller, 1971; Schaller and Harris, 1975). According to Braine, a major factor contributing to developmental changes in the perception of the upright is that older children scan figures from the top downward regardless of the location of salient features. (This is consistent with the view of many theorists that with increasing development children's attention is less likely to be caught by perceptually salient details; Braine has pointed out, for example, the similarity to Piaget's discussion of decreasing centration.) A second factor is that children with greater experience with symbols are likely to have their judgments of the upright biased by the resemblance of an abstract form to a familiar symbol with a conventional upright.

The Perceived Upright and Recognition Accuracy

Some support for Braine's theory concerning children's internal scanning procedures is provided by research relating the orientation of two dimensional figures to the ease with which the figures can be recognized. If the young child scans a figure sequentially from the focal feature downward, then for a figure that is presented very briefly, the child should miss the portion located above the focal feature. The child should be

most likely to scan a whole figure and to identify it correctly if its focal feature is at the top, i.e., if the figure is perceptually upright; the child should be least likely to identify the figure if the focal feature is located near the bottom with the information needed to identify the figure near the top. In contrast, if the older child uses a consistent top-to-bottom scanning procedure, he or she should identify figures most accurately when the distinguishing characteristic of each figure is at the top regardless of the location of the focal feature. Braine (1972) has found exactly this pattern of results for simple figures with clear focal features.

The relationship between orientation and recognition accuracy disappears when figures can be viewed for unlimited time (Braine, 1972), a result which is consistent with Braine's internal scanning hypothesis since children would be able to go back and look at portions of a figure missed during the initial scanning of the figure. Practically, this implies that a discrepancy between the perceived upright and the conventional upright of a letter should have little influence on children's ability to identify the letter under normal viewing conditions. As soon as the child tries to respond to strings of letters (such as words), however, perceived orientation may play a more significant role—processing of letter strings may be more difficult when the location of the perceived top shifts from letter to letter within the string. (Readers interested in the relation between orientation and shape processing for strings of letters are referred to Frith's chapter in this volume and to the work of Kolers and Perkins, 1969a, 1969b, 1975.)

Perception of the Upright and Copying Errors

Children's rotation errors in writing and copying figures often appear to be attempts to produce the figures in a perceptually upright orientation, possibly as a result of a tendency to form perceptually upright memory representations (Braine, 1973).

Eldred (1973) has provided the most clear-cut evidence that figure rotations tend to be rotations to the upright. She asked preschool children to copy abstract forms and also obtained the children's judgments concerning the orientations

that were upright versus upside-down. The children almost never rotated figures that were presented in their judged upright orientation, but frequently rotated other figures to their perceptually upright orientation.

Finally, there is intriguing evidence suggesting a link between the perception of the upright and the rotation errors made by school-age children with a variety of disabilities on perceptual-motor tests such as the Bender-Gestalt. Braine (1973) reports an analysis of rotation errors by a heterogeneous group of abnormal children between the ages of 7 and 15 years. For two figures that had a clear perceptual upright according to the criteria discussed above, almost all of the 90° rotations were ones that resulted in perceptually upright figures. In a further pilot study, Braine found that another sample of atypical children produced no rotations of figures that were presented in the perceptually upright orientation but did produce rotations (to the upright) of figures presented rotated 90° from that orientation. Finally, Braine (1978) reports preliminary results from a dissertation by Pamela Perkins in which the rotation errors made by children with learning disabilities in copying more complex figures disappear when the figures to be copied are presented in their perceptually upright orientation.

Results such as those cited above have lead Braine (1974) to suggest that parents or teachers wishing to correct children's letter rotations should note whether the rotations make the letters perceptually upright (e.g., inverting *V*). When this is the case, it may be helpful if the adult acknowledges that the letter may appear right to the child as he or she has made it, but explains that by convention we are supposed to make it a different way.

Perception of the Upright and Plane of Presentation

Braine (1974) notes that evidence concerning the child's early interpretation of the upright is more clear-cut for figures presented in a frame of reference for which the top corresponds to the gravitational upright than for a flat figure on a horizontal surface. The child's everyday experience provides many cues concerning the direction that is "up" with respect to

gravity, but the child has to learn arbitrary conventions designating the "top" of a paper or figure on a horizontal surface. In considering the effects of plane of presentation on children's orientation judgments, one has to be careful about the terminology used—orientation concepts that are closely related for an adult may not be for the child. If the child's judgment of the perceptually upright is a judgment that a figure "looks right" because of the ease with which the child can process a retinal image oriented in a given way, then plane of presentation should not influence the orientation judged by children to be right-side-up; consistent with this, Braine (personal communication) has obtained preliminary results suggesting moderate agreement concerning the "right" orientation of a figure in horizontal and vertical planes. However, the basis for the judgment of the location of the top of a figure or card seems to be quite different from the "looks right" judgment, probably depending more on learned conventions and influenced to a greater extent by the degree of agreement between gravitational and other cues.

Summary and Evaluation

In summary, preschool children are willing to make judgments concerning the correct and incorrect orientations of abstract two dimensional figures; and for many simple figures children from various backgrounds agree on the "correct" orientation. After age five, children show less consensus concerning the correct orientation of unfamiliar abstract figures, and they also begin to make comments indicating that the task does not make sense to them. It should be noted, however, that the age estimates are based on data collected prior to the era of Sesame Street and the Electric Company; to the extent that age changes are the result of experience with letters, these age estimates are probably no longer completely accurate for American preschool children. Young children's judgments of the upright have been shown to relate to other aspects of their ability to deal with forms. They are better able to recognize rapidly presented figures that are perceptually upright than ones that are upside-down, and their errors in copying figures are sometimes rotations of the figures to the perceptually upright position.

Braine explains the above phenomena by proposing that the child has a natural internal scanning procedure for processing visual stimuli, that figures are perceived to be upright in the orientation for which this scanning procedure works best, and that figures are most readily recognized in the perceptually upright orientation because it is the one for which the scanning procedures work best.

Braine's theory is appealing because of the variety of observations it ties together. However, there are issues concerning her theory that need to be clarified. Probably the most important is the need for an a priori definition of a "focal feature" (or another way of specifying the perceived upright) that works for more than very simple figures. A second issue, shared by many other information-processing analyses, is what one means by "internal scanning" and the extent to which it mimics overt scanning. A third issue concerns the difference between the processing of familiar and unfamiliar forms. As discussed above, Braine interprets evidence that children recognize geometric forms most easily in their perceptually upright orientation as suggesting a tendency to form perceptually upright memory representations. However, Braine has also shown that young children recognize realistic figures most readily when displayed in their usual orientation (Ghent, 1960); she proposes that children form memory representations of these figures that are "ordered" from top to bottom. (She states that realistic figures are likely to be too complex to have a single focal feature and therefore are likely to be scanned from top to bottom even by young children.) It is an interesting question how experience might influence young children's memory representations of symbols such as the letter *V* for which there is a perceptually upright orientation that differs from the conventional upright.

Whether or not all of the details of Braine's theory turn out to be supported, it is clear that young children have concepts of the upright for both familiar and unfamiliar two dimensional forms, and that these concepts influence the children's ability to recognize and copy the forms. The early concept of the upright, however, is a relatively primitive spatial concept since it requires articulation of only one pole of one axis of two dimensional space.

Confusions of Left-Right Mirror Images

Children's early sensitivity to the upright does not seem to be accompanied by comparable sensitivity to the left-right orientation of asymmetrical figures. This is consistent with Braine's theory, since she proposes a natural early coding system for the upright based on a downward internal scanning mechanism, but no comparable natural coding system for left-right differences. However, we cannot rule out the existence of any early ability to encode left-right asymmetries without more information concerning infants' responses to tasks requiring mirror-image discriminations.

For older preschool children, at least four factors can be shown to contribute to confusions of left-right mirror images. They include 1) failure to attend to left-right orientation, 2) use of relative orientation codes different from those used by adults in comparable situations, 3) memory limitations, and 4) use of motor strategies that make some symbols easier to copy and write in reversed orientation. Each of these factors are discussed in more detail below.

Selective Inattention to Left-Right Orientation

Children frequently fail to use left-right orientation information that they are capable of discriminating, a conclusion indicated by studies in which training improves performance on mirror-image discrimination tasks (Caldwell and Hall, 1969; Hendrickson and Muehl, 1962; Jeffrey, 1958, 1966; Koenigsberg, 1973). These studies use a variety of techniques; the major common characteristic is that they emphasize the relevance of orientation, giving the child experience concerning the importance of attending to the way in which a figure is turned or is facing. For example, Caldwell and Hall gave children experience in fitting an overlay (a line drawing on a transparent sheet) so that it fit exactly on top of a standard figure and then on top of matching figures; they emphasized that the figures were the same only if the child did not have to turn the overlay in moving it from the standard to the match.

In the absence of specific training, it is probable that children frequently ignore the left-right orientation of two dimensional forms because they overgeneralize from their

experience with object constancy. The child who is learning to identify symbols typically has had years of experience with objects whose names do not change no matter how the objects are oriented—at least as long as their orientation with respect to gravity is preserved. Thus a cup is a cup regardless of the side on which the handle appears. Letters and numbers are the first "objects" the child encounters for which left-right orientation bears any relation to object identity. In contrast, many objects do have an upright with respect to gravity to which the child must attend; for example, the contents of a cup will spill if the cup is not upright. The probable existence of a link between the child's experience with objects and left-right orientation confusions in learning symbols was pointed out by Davidson as early as 1935.

Even when children begin to realize that left-right orientation can be important, they seem to treat it as low priority information that they are less likely to use than other characteristics. For example, they are less likely to mention an orientation change than a location change when both are present (Stein and Mandler, 1974, 1975).

Use of Relative Orientation Codes

Even when children know that it is relevant to pay attention to left-right orientation, they continue to make some reversal errors. Children's pattern of errors on simultaneous comparison tasks implies that the children frequently are not ignoring orientation, but rather are using orientation concepts different from those normally used by adults in comparable circumstances. This is particularly apparent in children's tendency to confuse pairs of mirror images that form a symmetrical pattern around the boundary between them. It is well established that children are more likely to confuse left-right mirror images when they are aligned horizontally, as shown on the left of Figure 2, than when they are aligned vertically, as shown in the center of Figure 2; conversely, they are more likely to confuse up-down mirror images in vertical alignment than in horizontal alignment (e.g., Cairns and Steward, 1970; Huttenlocher, 1967a, 1967b; Sekuler and Rosenblith, 1964). Children are also more likely to confuse

symmetrically aligned mirror images than ones aligned along their diagonal, as shown on the right side of Figure 2, with performance in the diagonal conditions being as least as accurate as that for more typical non-symmetrical alignments (Chapman, 1970; Enterline, 1970; Vogel and Laughlin, 1978). Indeed, on discrimination-learning tasks in which children must remember from trial to trial which of two mirror-image alternatives is the correct choice, learning generally is faster when the alternatives are presented successively than when they are presented simultaneously in symmetrical alignment (Thompson, 1975; Williams and Ackerman, 1971).

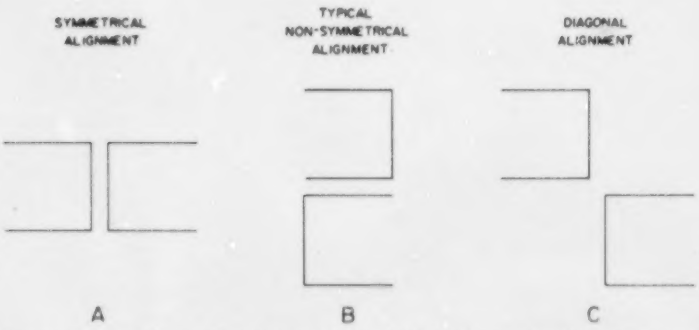

Figure 2. Three types of alignments of stimuli used in simultaneous mirror image discrimination tasks.

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Barroso and Braine (1974) have demonstrated that the alignment effects reflect a general spatial comparison strategy that is also elicited by non-mirror image displays presented in the appropriate configuration. Thus they showed that three-year-olds who were instructed to place pairs of non-identical figures so that they were "turned the same way" showed a

typical pattern of alignment effects, making left-right reversals for horizontally aligned sideways figures and up-down reversals for vertically aligned upright and upside-down figures.

The most plausible explanation for the alignment effects seems to me to be that the salience of the boundary between the symmetrically aligned figures induces children to make relative orientation judgments, orienting the figures so that they are the same with respect to this boundary. Children may often reduce left-right discriminations to topological distinctions of proximity to landmarks, e.g., "toward-the-window" versus "toward-the-door." When children compare horizontally aligned displays, they are likely to use the boundary between the displays as a referent and orient figures or judge distances so that they are the same with respect to this boundary. Under other alignment conditions—in the absence of a salient common boundary between displays—children are likely to use a referent that is on the same side of both displays. For up-down mirror image pairs, the prominence of the boundary between figures may also lead to use of relative orientation judgments instead of use of the distinction between right-side-up versus upside-down. (As would be expected given a clearer distinction for right-side-up versus upside-down than for left-facing versus right-facing, even for symmetrically aligned pairs children generally make fewer up-down mirror image confusions than left-right mirror image confusions.) When children develop an internal frame of reference that does not depend on use of landmarks in the visual field, their earlier use of landmarks may lead to the development of an alternate, relative orientation concept, i.e., that figures are oriented the same way when they are the same with respect to a boundary between them. Evidence consistent with this proposal is that adults' response latencies on mirror image discrimination tasks shows a pattern of alignment effects parallel to that for children's errors (e.g., Wolff, 1971), as if adults also have absolute and relative orientation concepts and need to suppress the inappropriate one under symmetrical alignment conditions.

The existence of alignment effects, whatever their interpretation, has clear practical implications. If one wants to

teach a young child to attend to left-right orientation, then initially one should avoid presenting the stimuli to be discriminated in a horizontal row since that spatial arrangement maximizes the child's chance of confusion. It would be interesting to know how many prereading workbooks present exercises in discrimination of left-right orientation in the form of horizontal rows containing a standard and a series of comparison figures.

Memory Limitations

Children who are able to notice left-right orientation differences still often have difficulty in remembering these differences; for example, children are more likely to make reversal errors when writing from dictation than when copying letters and numbers (Asso and Wyke, 1971; Hildreth, 1932). In general, tasks that require memory for the left-right orientation of a figure are more difficult than orientation discrimination tasks that do not require memory (Bryant, 1969, 1973; Over and Over, 1967; Samuels, 1969; Wechsler and Hagin, 1964).

It is useful to think about the nature of the young child's difficulty in remembering left-right orientation in relation to research indicating that there is a sequence of stages or processes through which visual information passes from stimulation of the receptors of the eye to relatively permanent memory store. In general, processing has been divided into three phases. There is a brief period of 1/4 to 1/2 second after receptor stimulation during which most of the information from a visual stimulus seems to be available in relatively uncoded form (see Averbach and Sperling, 1961). To be retained longer, information must be encoded actively into short-term memory. Other processes are thought to be necessary to retain information in more permanent, long-term memory.

There is evidence that young children may have difficulty retaining information concerning left-right orientation in their short-term memory representations of a visual stimulus. The likelihood of a child's retaining left-right orientation information is influenced by both the length of

time the stimulus is available for processing and the amount of information to be processed. Thus in a tachistoscopic study (Vogel, 1973) five-year-olds who had been trained to make orientation discriminations needed longer availability of an abstract figure to encode its orientation into short-term memory than to encode information sufficient for a general shape discrimination, and children who knew that they would have to remember orientation on specific trials were able to remember this characteristic more accurately than children who were told only that they would be tested on either orientation or general shape. The latter observation is consistent with the conclusion stated earlier that left-right orientation is low-priority information—it seems more likely to be ignored than other characteristics when there is an information overload. In contrast to young children, adults appear to be able to encode information sufficient for a left-right mirror image discrimination as rapidly as information sufficient for a general shape discrimination (Vogel, 1977a).

The evidence concerning short-term memory for orientation is useful for explaining why young children can seem capable of remembering orientation at one time or on one task but not at another time or on another task. Thus the child who can remember orientation when he or she is allowed to concentrate on this characteristic may have difficulty retaining such information when it is necessary to attend to other characteristics at the same time, and the child who remembers the orientation of a single figure quite accurately may scan a complex array such as a written page too rapidly to encode orientation information.

The retention of information concerning the left-right orientation of a figure for a few seconds in short-term memory does not insure that this information will be available in the child's longer term representation of the figure. Thus in a recognition-memory study, five-year-olds had little difficulty remembering the left-right orientation of a picture immediately after seeing the picture; but when they saw a series of 10 or 20 pictures and then were asked to choose between the pictures and their mirror images, the children's performance was barely above chance level (Vogel, 1977b). Older children and adults are more likely to retain left-right orientation informa-

tion in long-term memory than are five-year-olds (Mandler and Day, 1975; Vogel, 1977b). However, five-year-olds can be induced to remember left-right orientation if they are given a specific code for orientation, for example if they are asked to name a detail on "their" side of each picture versus one on the side nearer to another person; and their long-term memory for orientation also improves if they are simply induced to give detailed verbal descriptions of the pictures, presumably because this ensures thorough processing of them (Vogel, 1977b; 1979).

Like normal younger children, children who have difficulty learning to read may sometimes be a byproduct of mirror images on tasks that require memory (Wechsler and Hagin, 1964; Sidman and Kirk, 1974), and it is an interesting possibility that the persisting reversal errors of children with difficulty learning to read may sometimes be a byproduct of more general memory limitations. There is recent evidence that dyslexic children have difficulty encoding items in an array into short-term memory, although they and their normal peers initially have equivalent information available (Morrison, Giordani, and Nagy, 1977); this difference parallels a developmental difference between five-year-olds and older children (Morrison, Holmes, and Haith, 1974; Sheingold, 1973). Similarly, dyslexic children might require longer to encode information from single visual forms (Stanley, 1975), again parallel to a difference between younger and older children (see Day, 1975). Thus children with difficulty learning to read may be particulary susceptible to information overloads and therefore to difficulty in encoding low-priority orientation information. Consistent with the view that mirror image confusions reflect more general encoding limitations, there is some evidence that poor readers who make mirror image confusions tend to make other kinds of visual confusions as well (Liberman, Shankweiler, Orlando, Harris, and Bell Berti, 1971). Finally, with respect to long-term memory, there is evidence that in the primary grades good readers may have memory representations of letters that include more strongly articulated information about left-right orientation than do poor readers (Frith, 1974).

Writing Strategies and Orientation Errors

Some reversal errors in writing and copying may be caused by children's motor strategies. Thus Goodnow and Levine (1973) have shown that righthanded children tend to copy shapes by making strokes from top to bottom and left to right. Their four- and five-year-old subjects were less likely to reverse figures that were easily formed according to these rules (*b*-like figures) than ones whose mirror images could be formed more easily by the rules (*d*-like figures). Consistent with this, Lewis and Lewis (1965) report an analysis of first-grade children's copying errors in which reversals of *d* and *q* were approximately two to three times as frequent as reversals of *b* and *p*. Left-handed children tend to make strokes from right to left rather than from left to right (Lehman and Goodnow, 1975). It would be interesting to note whether they also make different reversals than do righthanded children.

Braine (1974) has suggested that some rotation errors could be caused by the writing strategies just described. For example, a child's copying of *G* by beginning at the top left of the space and moving downward might result in ↻.

It is not clear what role writing strategies play in the persisting reversals of children with reading difficulty. However, there is considerable evidence that difficulty in sequencing information is characteristic of many dyslexic children (see Benton, 1975). This has led me to wonder whether some children who have difficulty in sequencing compensate for this by maintaining rigid left-to-right orders even when forming letters that cannot be made properly with left-to-right strokes, thus reversing letters such as *C*, *S*, and *d*.

Summary and Conclusions

In this chapter I have argued that young children's orientation errors with letters and numbers are a direct consequence of the children's orientation concepts and processing strategies.

The child's first orientation concept is one of the upright. Even unfamiliar figures are frequently perceived as having one correct or upright orientation on the basis of perceptual

characteristics. For some symbols the "perceptual upright" does not agree with the conventional upright orientation, and many rotations appear to be attempts to produce forms in their perceptually upright orientation.

Initially the young child seems not to realize that left-right orientation is relevant to the identity of symbols, and the child's failure to pay attention to this characteristic leads to confusions of left-right mirror images. Even when the child realizes that orientation can be relevant, it is low-priority information that is less likely to be noticed than other characteristics.

Children's strategies for comparing simultaneously presented mirror images lead the children to be particularly likely to confuse symmetrically aligned mirror images. This confusion of symbols under highly specialized circumstances probably has little direct significance for the use of letters in normal reading and writing. However, the alignment effects probably influence performance on prereading exercises and reading readiness tests since these materials often include orientation discrimination tasks which are presented so that mirror images are symmetrically aligned.

Children who can make left-right orientation discriminations frequently still have difficulty remembering orientation information and are less likely to remember orientation than other characteristics. Even when the child does remember left-right orientation for a brief period, he or she may not retain this information in long-term memory.

Reversal errors in writing and copying may be a result of any of the factors discussed above. In addition, both reversals and rotations may reflect the child's writing in the manner that conforms most easily to natural motor-production rules.

For most children orientation confusions decrease rapidly during the early school years and thus should be a cause for minimal concern and intervention. However, if one does want to deal with orientation errors in a reading readiness program or to deal with the persisting orientation confusions of older children, the material presented in this paper has practical implications. To the extent that a teacher or parent can analyze a situation and figure out the specific bases for a child's rotation and reversal errors, the parent or teacher can

respond appropriately. Under some circumstances it may be appropriate to point out that the child's interpretation of a task seems to differ from an adult interpretation. Thus a child might be told that a rotated *V* may look better rotated, but it is usually written so that it looks upside down; or a child making reversal errors might be given training to make sure that the child realizes that the left-right orientation of symbols matters. Sometimes a change in materials might be helpful. For a child who makes many rotations, a slanted easel might be substituted for a flat desk in order to give the working surface a clear top. Similarly, if a page of materials involving symmetrically aligned mirror images is giving children considerable difficulty, the layout of the materials on the page might be changed. In some cases patience may be the best approach. For example, the child who makes reversal errors only with some materials, or only when tired, may do so because there is an information overload with orientation being low-priority information. If this is the case, then the use of orientation information should improve as the child becomes more adept at handling other competing information. Finally, an indirect strategy sometimes may be useful. For some children who are making orientation errors and are also having difficulty with other aspects of reading, helping the child to deal with the other difficulties may reduce the complexity of the child's task and increase the probability that the child will pay attention to low-priority orientation information.

This paper has dealt primarily with the bases for orientation confusions in normal children who are beginning to learn to read and write. The most important question raised by this material is whether the factors discussed also contribute to the persisting errors made by some older children. Evidence has been mentioned that rotation errors by children with learning disabilities, like those of normal younger children, tend to be rotations to the perceptual upright. Findings of memory encoding limitations and sequencing problems in children with reading difficulties have led to two hypotheses concerning these children's persisting mirror image confusions. First, some persisting reversal errors may be a byproduct of more general memory encoding limitations—to the extent that children have difficulty encoding informa-

tion into memory, they should be particularly likely to lose low-priority orientation information. Second, children who have difficulty retaining information about order in a sequence may overcompensate in their writing, maintaining rigid left-to-right order of strokes even when this results in writing some letters backwards. Whether or not these specific hypotheses will be supported by future research, the analysis of factors relevant to normal children's orientation errors provides a frame of reference for examining the bases for the persisting errors of children who have difficulty learning to read.

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Footnotes

[1]The starting point of this paper was my discussions with Uta Frith after hearing Lila Braine's presentations at the SRCD Institute on Reading and Child Development in June 1974, and the ideas have been influenced by many discussions with Lila Braine since then. I am grateful to Lila Braine, Carol Santa, and Martha Teghtsoonian for their detailed comments on an early version of this paper, and to Sheldon White and the Harvard Center for Behavioral Sciences for providing the summer office and congenial working atmosphere in which it was written. The chapter's title was straightened out as a result of a conversation with Shep White and Jane Platt. The preparation of this paper was partially supported by a grant from the Rutgers University Research Council.

[2]There are some exceptions to Braine's rules for determining a focal feature even for shapes that intuitively are very simple. Thus circles and rectangles with one gap in their contours have been judged upright with the gap at the bottom or have failed to elicit consistent preferred orientations (see Ghent, 1961, Figure 1).